PRELIMINARY FINDINGS ON THE TEMPOROMANDIBULAR JOINT SOUNDS OF LATERAL CROSS-BITE PATIENTS

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ABSTRACT

In this paper we investigate the relation between lateral cross-bite disorders and the sounds generated by the Temporomandibular Joint (TMJ). TMJ vibrations are recorded clinically by palpation and auscultation and also electronically by accelerometers. TMJ signals are filtered, amplified, digitized and stored on a computer. Based on joint time-frequency moments calculated from evolutionary spectrum, sounds are categorized into four classes. Palpation, auscultation and time-frequency classification findings are presented.

1. INTRODUCTION

Temporomandibular joint (TMJ) is located between the temporal bone and the mandible. It consists of the mandibular condyle, articular disc, temporal fossa, muscles and ligamants. One of the most common Temporomandibular Joint disorders is joint sounds. Palpation and auscultation are valid procedures in the diagnosis of joint sounds [1]. Although some investigators have stated that joint sounds are related to orthodontic malocclusions, a concencus has not been reached [2, 3, 4, 5]. Orthodontic treatment is a treatment option in the treatment of temporomandibular disorders, as well as it may be the cause. One of the orthodontic malocclusions stated to be the cause of TMJ sounds in lateral crossbite [6]. Lateral crossbite is the palatal position of upper buccal teeth in comparison to lower buccal teeth. It may be unilateral or bilateral.

In this work, we examine the crosssbite patients by using palpation and auscultation methods and also electronically record TMJ sounds. Then we perform a time-frequency analysis of the recorded TMJ sounds.

The analysis of recorded TMJ sounds offers a powerful non-invasive alternative to the old clinical methods such as palpation, auscultation, and radiation. In the first studies, the time–amplitude waveforms of TMJ sounds are analyzed. However, it is not possible to characterize signals just based on their time behavior [7]. Power spectral analysis has also been used in the analysis of TMJ sounds to obtain the distribution of signal energy over a frequency range. However, a disadvantage of conventional power spectra is that completely different time signals can have exactly the same power spectra [8]. In other words, for non–stationary signals like TMJ sounds, it is required to know how the frequency components of the signal change with time. This can be achieved by obtaining the distribution of signal energy over the time–frequency (TF) plane [8].

Here we use the evolutionary spectrum based on multi–window Gabor expansions for the TF analysis and classification of TMJ sounds. The multi–window Gabor expansion represents a signal in terms of basis functions that are scaled and translated windows modulated by sinusoids [9]. An evolutionary spectral estimate is obtained from the coefficients of this Gabor expansion.

2. TIME-FREQUENCY ANALYSIS OF TMJ SOUNDS

In this section, we briefly present the signal analysis technique we use to investigate TMJ signals. Time-frequency (TF) signal analysis provides a characterization of signals in terms of joint time and frequency content [8, 10]. The main concern of the TF analysis is obtaining the distribution of signal energy over joint TF plane with a high concentration [8]. In the last two decades, vast amount of work have been done to develop TF signal analysis methods [8]. The short-time Fourier transform (STFT), Cohen's class of bilinear TF distributions (TFDs), positive TFDs, wavelet and Gabor type of TF representations (TFRs), and Priestley's evolutionary spectrum are among the main approaches to the TF analysis [11].

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The Gabor expansion is one of the TF analysis methods which represents a signal in terms of time and frequency translated basis functions, $h_{m,k}(n)$, called TF atoms [12]. In [11], a multi-resolution Gabor expansion is presented, as such a finite-extent, discrete-time signal $x(n)$ can be represented by

$$x(n) = \frac{1}{I}\sum_{i=0}^{I-1}\sum_{m=0}^{M-1}\sum_{k=0}^{K-1} a_{i,m,k}\; \tilde{h}_{i,m,k}(n), \tag{1}$$

where the logons are

$$\tilde{h}_{i,m,k}(n) = \tilde{h}_i(n - mL)\; e^{j\omega_k n}, \tag{2}$$

and $\omega_k = 2\pi k L'/N$. The parameters M, K, L, L' are positive integers constrained by $ML = KL' = N$ where M and K are the number of analysis samples in time and frequency, respectively, and L and L' are the time and frequency steps, respectively.

The synthesis window $\tilde{h}_i(n)$ is the periodic version (by N) of $h_i(n)$ which is generated by contracting a unit-energy mother Gabor window $g(n)$, i.e.,

$$h_i(n) = 2^{i/2}\; g(2^i n), \qquad 0 \le n \le N-1, \tag{3}$$

for $i = 0, 1, ..I-1$. The scaling factor 2^i changes the support of the window, and I is the number of scaled windows used to analyze the signal. The Gabor coefficients are evaluated by

$$a_{i,m,k} = \sum_{n=0}^{N-1} x(n)\; \tilde{\gamma}_i^*(n - mL)\; e^{-j\omega_k n}, \tag{4}$$

where the analysis window $\tilde{\gamma}_i(n)$ is again a periodic version of $\gamma_i(n)$ which is solved from the bi-orthogonality condition between $h_i(n)$ and $\gamma_i(n)$ as in the discrete Gabor expansion [11].

Notice that equation (1) is the average of I representations of $x(n)$. However, each of these expansions represents some of the signal components better than others. Hence the TF resolution of this representation is improved by averaging several representations obtained from scaled windows.

2.1. Evolutionary Spectral Analysis

We consider the following discrete-time, discrete-frequency model for finite-extent, deterministic signals:

$$x(n) = \sum_{k=0}^{K-1} A(n, \omega_k) e^{j\omega_k n}, \qquad 0 \le n \le N-1, \tag{5}$$

where $\omega_k = 2\pi k/K$. The multi–window Gabor expansion in (1) can be written as

$$\begin{aligned} x(n) &= \sum_{k=0}^{K-1} \frac{1}{I}\sum_{i=0}^{I-1}\sum_{m=0}^{M-1} a_{i,m,k}\; h_i(n - mL)\; e^{j\omega_k n} \\ &= \sum_{k=0}^{K-1} A(n, \omega_k)\; e^{j\omega_k n}. \end{aligned} \tag{6}$$

We then have that the time-varying kernel of the signal is

$$\begin{aligned} A(n, \omega_k) &= \frac{1}{I}\sum_{i=0}^{I-1}\sum_{m=0}^{M-1} a_{i,m,k}\; h_i(n - mL) \\ &= \frac{1}{I}\sum_{i=0}^{I-1} A_i(n, \omega_k). \end{aligned} \tag{7}$$

Replacing the coefficients $\{a_{i,m,k}\}$ of equation (4) we obtain also that

$$A(n, \omega_k) = \sum_{\ell=0}^{N-1} x(\ell)\; \mathrm{w}(n, \ell)\; e^{-j\omega_k \ell}, \tag{8}$$

where we defined the time–varying window

$$\mathrm{w}(n, \ell) = \frac{1}{I}\sum_{i=0}^{I-1}\sum_{m=0}^{M-1} \gamma_i^*(\ell - mL) h_i(n - mL). \tag{9}$$

Then the evolutionary spectrum of $x(n)$ is obtained according to

$$S_{ES}(n, \omega_k) = \frac{1}{K}\; |A(n, \omega_k)|^2, \tag{10}$$

where the factor $1/K$ is used for proper energy normalization. $S_{ES}(n, \omega_k)$ is always non–negative and approximates the marginal conditions [8], hence, in contrast to many time-frequency distributions, interpretable as TF energy density function [11].

2.2. Classification of TMJ Sounds Using Joint Moments

It was reported in earlier work [7, 13] that time–varying characteristic features of temporomandibular joint signals are revealed by joint time–frequency analysis better than time or frequency domain techniques. It is then natural to expect that time–frequency information of non–stationary signals, such as TMJ sounds, should improve the classification performance [14, 15]. In [9], we present a method for the classification of TMJ sounds based on the evolutionary spectrum discussed in the previous section. For each data in the training set, evolutionary spectrum is calculated and normalized to unit–energy. Then several joint moments are obtained from the evolutionary spectrum and used as features for the classification.

The joint time–frequency moments are given by

$$< t^i, \omega^j >= \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} t^i \; \omega^j \; X(t, \omega) \; dt \; d\omega \qquad i, j = 0, 1, 2, ... \tag{11}$$

where $X(t, \omega)$ is the time–frequency density function of the signal [8]. In our experiments, we calculate joint moments of TMJ signals by using $S_{ES}(n, \omega_k)$ and numerical approximations for the integrations in (11). The joint moments are then log–normalized to reduce their dynamic range. This feature set is then used to train a neural network for the classification of TMJ sounds [16]. In [9], TMJ sounds are classified into four distinct classes: a) click, b) coarse crepitation, c) soft crepitation, and d) click with crepitation.

3. MATERIAL AND METHOD

The material consists of 10 females and males with right lateral crossbites. Their ages are between 9-13 years. Full orthodontic records consisting of cephalometric films, frontal and sagittal intra and extra-oral slides, panoramic films, orthodontic models, anamnestic and clinical records were obtained from each patent. A questionnaire and an examination form prepared by Dworkin et al. [17] were used in their Turkish translated form; dental parameters were recorded by a single investigator. TMJ vibrations were clinically recorded by palpation, auscultation and electronically by accelerometers. TMJ signals are filtered, amplified and digitized to store on a computer. Palpation and ausculation records and three examination variables (maximum opening capacity, deviation of the lower jaw to right or left, midline shift) were statistically evaluated.

Findings:

(i) Palpation findings: In nine subjects, palpation findings showed no sound on either joint. In one subject, clicking was present only on the cross-bite side.

(ii) Auscultation findings: No sound was found in nine subjects. Clicking was present on both sides in one subject.

(iii) Time-frequency based classification findings: In 4 out of 9 cases, soft crepitation was present on both TMJs. In the rest of the cases, the following combinations were found:

1. Bilateral clicking was present on both sides
2. Click and soft crepitation on one side, coarse crepitation on the other side
3. Soft crepitation on one side, click and coarse crepitation on the other side
4. Coarse crepitation on both sides
5. Click and coarse crepitation on one side, coarse crepitation on the other side.

The quantity of the cases did not render the study group sufficient for statistical evaluation. In Fig. 1 we show the TMJ sound for 5 secs. recorded from lateral crossbite patient. Figs. 2 and 3 show the evolutionary spectral estimates of these click sounds for right and left TMJ respectively.

4. RESULTS AND DISCUSSION

In this paper, we analyzed the TMJ sounds recorded from lateral crossbite patients. As can be understood from the findings, palpation and auscultation values are fairly similar. When auscultation is used as a standard, surface palpation has a very high false negative rate [18]. Auscultation is found more sensitive than palpation in another study as well [19]. However, recordings were carried out by a single investigator in our study, thus excluding the possibility of inter-researcher unreliability. Since Temporomandibular disorders are highly prevalent in the mixed and early dentition groups as well as in other dentition groups [19], the significance of the cilcks and crepitations must be investigated further by increasing the number of cases and by comparing the clinical variables.

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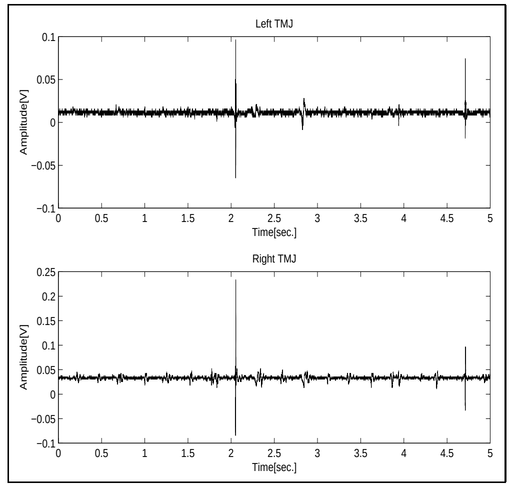

Fig. 1. TMJ signal of a crossbite patient with click

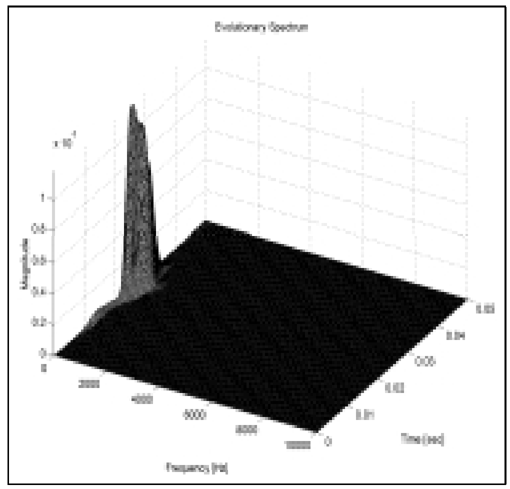

Fig. 2. Evolutionary spectrum of the right TMJ click

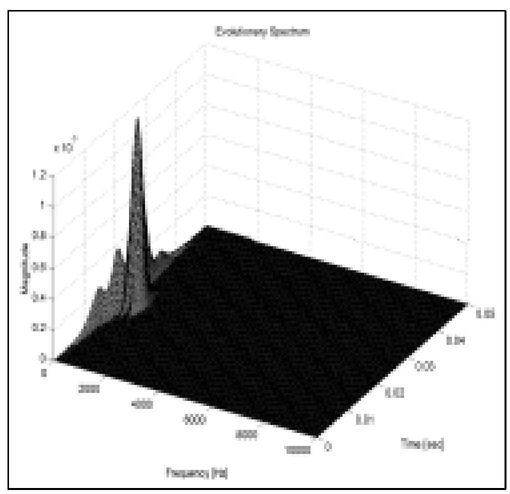

Fig. 3. Evolutionary spectrum of the left TMJ click